Available online at www.sciencedirect.com
ScienceDirect
Renewable and Sustainable Energy Reviews
11 (2007) 497–511

RENEWABLE
& SUSTAINABLE
ENERGY REVIEWS

www.elsevier.com/locate/rser

Geothermal energy potential for power generation in Turkey: A case study in Simav, Kutahya

Ramazan Kose*

Department of Mechanical Engineering, Dumlupinar University, 43100 Kutahya, Turkey

Received 4 January 2005; accepted 5 March 2005

Abstract

Geothermal energy and the other renewable energy sources are becoming attractive solutions for clean and sustainable energy needs of Turkey. Geothermal energy is being used for electricity production and it has direct usage in Turkey, which is among the first five countries in the world for the geothermal direct usage applications. Although, Turkey is the second country to have the highest geothermal energy potential in Europe, the electricity production from geothermal energy is quite low. The main purpose of this study is to investigate the status of the geothermal energy for the electricity generation in Turkey. Currently, there is one geothermal power plant with an installed capacity of 20.4 MWe already operating in the Denizli–Kizildere geothermal field and another is under the construction in the Aydin–Germencik field.

This study examines the potential and utilization of the existing geothermal energy resources in Kutahya–Simav region. The temperature of the geothermal fluid in the Simav–Eynal field is too high for the district heating system. Therefore, the possibility of electrical energy generation by a binary-cycle has been researched and the preliminary feasibility studies have been conducted in the field. For the environmental reasons, the working fluid used in this binary power plant has been chosen as HCFC-124. It has been concluded that the Kutahya–Simav geothermal power plant has the potential to produce an installed capacity of 2.9 MWe energy, and a minimum of 17,020 MWh/year electrical energy can be produced from this plant. As a conclusion, the pre-feasibility study indicates that the project is economically feasible and applicable.

Keywords: Binary cycle; Electricity generation; Geothermal energy; Geothermal power plant; Turkey

*Tel.: +90 274 265 20 62; fax: +90 274 265 20 66.
E-mail address: rkose@dumlupinar.edu.tr.

1364-0321/$ - see front matter
doi:10.1016/j.rser.2005.03.005

Contents

1. Introduction

With increasing awareness of the detrimental effects of fossil fuels on the environment as a result of incomplete combustion, there has been an increasing interest worldwide in the use of clean and renewable energy sources. Renewable energy technologies are clean sources of energy and this negative impact on the environment is much lower than the conventional energy technologies. In this regard, renewable energy resources appear to be a potential solution to energy and environmental problems and a key tool for sustainable development in the world. Geothermal energy, by nature, has high availability because the source is not dependent on weather conditions, so it is among the most stable renewable energy sources [1–7]. Among the renewable energy sources, the geothermal energy offers a good potential for producing electrical power with a high energy level in the short and medium terms. Also, geothermal energy systems are simple, safe, and adaptable with modular 1–50 MW plants capable of providing continuous base-load, load following, or peaking capacity and benign environmental attributes (negligible emissions of CO_2, SO_2, NO_x, and particulates).

The most stable renewable energy source is geothermal energy. Therefore, the geothermal power plants are designed to operate 24 h a day, and the operation is independent of the weather or fuel delivery [8]. The geothermal energy source that can be easily converted into electrical power is generally considered renewable, because reservoirs may be recharged by rain or by re-injection of the wastewater. Optimum utilization of a geothermal energy source, from an economical and thermodynamically point of view is strongly dependent on the characteristics of the geothermal fluid. Particularly, temperature, pressure, composition, and liquid to vapor ratio are important in determining the best method and conditions for the energy conversion [9,10].

Geothermal energy has been produced commercially for about ninety years and for four decades on the scale of hundreds of MW for both electricity generation and direct uses. Most of the world's geothermal power plants were built in the 1970s and 1980s following the 1973 oil crisis. Different authors have performed different estimations of the geothermal potential for both electricity generation and direct uses. The geothermal potential of the world to produce electricity should be between 35 and 72 GW. With the improving technology such as permeability enhancement, drilling improvements, this range could reach up to 138 GW [11]. The geothermal growth and development has increased significantly over the past 30 years approaching 15% annually in the early part of this period, but dropping below 5% annually in the last ten years due to an economic slow down in the far east and the low price of the competing fuels [12–14]. Geothermal power

plays a fairly significant role in the energy balance of some areas; for example, the electrical energy produced from geothermal resources represents the following percentages of the total electricity in various countries: 21.5% in the Philippines, 20% in Kenya, 20% in El Salvador, 17.2% in Nicaragua, 14.7% in Iceland, 10.2% in Costa Rica, 6.1% in New Zealand, and 5.1% in Indonesia. Today, this form of renewable energy has grown to 8771 MW in 25 countries producing an estimated 54,793 GWh/year of electrical energy [15]. Turkey's percentage of the total capacity is 0.25% of the total.

The present applications in Turkey have shown that the geothermal energy is a promising alternative and can make a significant contribution to avoid emissions of greenhouse gases. This paper discusses the potential for the geothermal energy use in Turkey. Although, Turkey is the second country to have the highest geothermal energy potential in Europe, the electrical energy generation from geothermal energy is quite low. Therefore, in this study, the potential of electricity generation by the binary cycle has been researched and the preliminary feasibility studies have been conducted in the Simav field.

2. Current state of electrical energy generation in Turkey

Turkey has been one of the fastest growing power markets in the world with its young and growing population, rapid urbanization, strong economic growth and low per-capita electricity consumption for two decades. Although almost all kinds of energy resources exist in Turkey, the resources other than the lignite and hydropower have not been used to meet the energy need of the country, and thus, more than half of the energy supply is provided by the importation [16–20]. The geothermal, hydropower, solar, wind, and biomass energies are the major resources to provide Turkey's energy needs in the future. Geothermal resources represent an important renewable energy source for Turkey, where the water and steam dominated geothermal fields exist and have been exploited for decades. Provided that the geothermal energy, which has a considerable potential in Turkey, is used for the electrical generation besides its usage for heating and greenhouses, the energy problem in Turkey will be remarkably solved. The recent developments have proven that the most important field of the geothermal energy usage in the future will focus on the electrical energy production.

In Turkey, electricity is produced by thermal power plants (consuming hard coal, lignite, natural gas and fuel oil), geothermal energy, wind energy and hydropower plants. Thermal resources meet approximately 61% of Turkey's total installed capacity for electrical power generation, while 80% of total electricity is generated from thermal power plants. Of the total thermal generation, natural gas accounts for 49.2%, followed by coal for 40.65, and 9.9% for liquid fuel [21]. Currently there are 15 coal-fired thermal plants in Turkey. In fact, coal is a highly efficient and cheap resource of energy for Turkey, also plentiful coal resources exist in Europe, but the quality of the lignite is not high and is suitable for use in the power plants. Turkey's second largest energy source after coal is hydro. Hydroelectricity is one of the most important renewable sources for electricity generation in Turkey. Turkey has a gross annual hydroelectric potential of 433,000 GWh, which is almost 1% of the world's total potential. In December 2002, there were 134 hydroelectric power plants in operation in Turkey [22]. These have a total installed capacity of 12,241 MW and an annual average generation capacity of 32,841 GWh. Presently, this generation meets about 19.5% of the electrical energy demand, it is still above the average of European union, which Turkey is expecting to be a member. The share of hydroelectric (renewable) and

lignite (national resource) was decreased while the share of natural gas in electricity generation increasing. Renewable, except hydraulic, have only very minor shares in power generation in Turkey: Geothermal accounts for 0.06% or 105 GWh, wind for about 0.03% or 57 GWh and combustible renewable for about 0.02% or 49 GWh [17,23–25]. The only operating geothermal power plant of Turkey is the Denizli–Kizildere geothermal power plant, located near the province of Denizli in Western Anatolia with an installed capacity of 20.4 MW. Hopes of ensuring a sustainable energy strategy lie in renewable energy sources as an alternative to fossil fuels.

At the end of 2002, Turkey's total installed power generation capacity reached 31845.8 MW, and 99.9% of its population was connected to the electricity grid. The main energy sources of the electricity production in Turkey and their contribution are shown in Table 1, and an historical summary of the installed capacity for electrical energy generation is shown in Table 2 [24–26]. It is clear from this table that the percentage of the electrical energy generation from the geothermal energy is very low; representing 0.06% of the total with a capacity of 105 GWh in 2002, but the projections foresees an improvement to 0.32% by the year 2020.

Because of the fast technological developments and growth, the electrical energy demand and need of Turkey is expected to continue in the foreseeable future. According to the predictions prepared by the ministry of energy and natural resources (MENR), the country will need an electrical power capacity of approximately 65 GW by 2010, and about 109 GW by 2020 [24,26]. Up to the end of 2020, and additional capacity of approximately 77 GW is required in order to meet the increasing demand of the country. This fact implies that a power demand growth rate of at least 8% per year is needed for the next decade. This would require investments of $4–4.5 billion per year, much of which would need to come from the private sector. If the relative percentage of the renewable energy sources as the total primary energy supply continues to decline, the domestic coal production and natural gas imports rise steadily to satisfy the rising electrical energy demand. As shown in Table 3, the largest growth is planned for the natural gas. However, there is a significant room for expanding the renewable energy use in Turkey, which has a large potential of biomass, geothermal, solar, and wind energy as well as hydro. In this regard, Turkey has to make use of its renewable resources, such as geothermal, wind, and solar, not only to meet the increasing energy demand, but also to reduce the environmental pollution.

Turkey expects a huge technological growth as its economy expands, and energy need in the form of electricity and natural gas, and has adopted a policy of encouraging foreign investments to establish and operate the power plants and natural gas pipelines to meet its

Table 1
Status of electricity generation in Turkey, 2002 [25]

Energy source	Installed capacity (MWe)	Installed capacity (%)	Annual generation (GWh)	Annual generation (%)
Fossil fuels[a]	19565.5	61.44	135,574	80.42
Hydro	12,241	38.44	32,841	19.49
Geothermal	20.4	0.06	105	0.06
Wind	18.9	0.06	57	0.03
Total	31845.8	100.0	168,577	100.0

[a]Fossil fuels includes hard coal, lignite, natural gas, and petroleum.

Table 2
Installed electricity generation capacity in Turkey, 1990–2002 (MWe) [25,26]

Power plants	1990	1995	1998	1999	2000	2001	2002
Thermal	9550	11,089	13,045	15,579	16,088	16,659	19565.5
Hydroelectric	6764	9862	10,306	10,537	11,175	11,672	12,241
Geothermal	20.4	20.4	20.4	20.4	20.4	20.4	20.4
Wind	0	0	1.5	8.7	18.9	18.9	18.9
Total	16334.4	20971.4	23372.9	26145.1	27302.3	28370.3	31845.8

Table 3
Electrical power capacity development in Turkey [17,18,27]

Energy source	2002		2010		2020	
	Installed capacity (MWe)	Generation (GWh)	Installed capacity (MWe)	Generation (GWh)	Installed capacity (MWe)	Generation (GWh)
Coal	7622.2	49744.5	16,106	104,035	26,906	174,235
Fuel oil and diesel	2244.3	14448.6	3125	17,993	8025	49,842
Natural gas	9699	71380.9	18,856	125,548	34,256	225,648
Nuclear	0	0	2000	14,000	10,000	70,000
Renewables[a]	12280.3	33,003	24,982	85,719	30,031	104,043
Total	31845.8	168,577	65,069	347,295	109,218	623,768

[a]Renewables includes hydropower, biomass, solar, wind, and geothermal energy.

anticipated energy demand. The MENR has accepted a policy that the most of the new power plants would be built by foreign developers on a "build-operate-transfer" (BOT) basis.

3. The potential and applications of geothermal energy in Turkey

Turkey does not possess enough conventional fossil fuel reserves, but possesses rich renewable energy resources such as geothermal, wind, solar, biomass, and hydro. By relying completely on indigenous resources, renewable energy resources (RES) would reduce reliance on imported fuels and enhance Turkey's energy security. The country has a place among the world's first seven countries with respect to abundance of its geothermal resources [28–33]. Much of this potential is of relatively low enthalpy that is; it is not suitable for electricity production but is still useful for direct heating applications. Before the 1960s, geothermal resources were only spontaneously in bathing and medical treatment in Turkey. The general directorate of mineral research and exploration (MTA) started the first geothermal research in Turkey in the 1960s [29]. The MTA has carried out some considerable geothermal energy research and explorations. Turkey's high enthalpy geothermal resources suitable for electricity production is estimated to produce 4000–4500 MWe of energy and its low enthalpy resources is estimated to have a

31,500 MWt energy, which could be used for district heating and other direct usages. While the high temperature geothermal resources have been used for power generation in Turkey, the intermediate and low temperature geothermal resources, which are widely distributed in Turkey, are mostly left unused, only a part of it is directly used for some purposes such as heating and bathing. Currently, approximately one hundred and seventy geothermal fields that can be useful at an economic scale, and about 1000 hot and mineral water resources with temperatures ranging from 20–242 °C, have been explored by MTA. At the end of 2002, Turkey's total installed capacity for direct heating was 992 MWt, of which about 665 MWt provided heating for 61,000 residences and $565,000\,m^2$ of greenhouses, and about 327 MWt was used to provide heated water for about 200 spas [30–34].

Geothermal resources of the country are wide spread but the favorable reserve for heating and generating electricity is limited and even this limited reserve has not yet been used. Parallel to the developments of the geothermal energy utilization in Turkey, it is planned that by the years 2010 and 2020, the total installed capacity will increase to 3500 MWt (500,000 residence equivalent, which is about 30% of the total residences in the country) and 8300 MWt (1,250,000 residence equivalent) for space heating, and to 500 and 1000 MWe for electricity production, respectively, [34,35].

Presently, nine geothermal fields in Turkey have a high enthalpy and have the necessary conditions for generating electricity in a binary cycle or flash plants. Conventional electrical power production is limited to fluid temperatures above 150 °C, but considerably lower temperatures can be used in binary cycle systems, also called organic Rankine cycles. In this cycle, the outlet temperatures of the geothermal fluid are commonly above 85 °C [1]. Fig. 1 illustrates nine geothermal fields of Turkey are suitable for generating electricity together with their possible utilization opportunities. High temperature geothermal fields suitable for conventional electricity generation are as follows: Denizli–Kizildere (242 °C), Aydin–Germencik (232 °C), Canakkale–Tuzla (173 °C), Aydin–Salavatli (171 °C), Aydin–Yilmazkoy (165 °C), Kutahya–Simav (162 °C), Manisa–Salihli (155 °C), Izmir–Seferihisar (153 °C), and Izmir–Balcova (126 °C) [36]. These fields may be evaluated if the government offers the financial and/or institutional support that is required for successful

Fig. 1. General tectonic and volcanic features and important geothermal fields of Turkey [31].

development. The three most important geothermal areas of West Anatolia, namely Denizli–Kizildere, Aydin–Germencik, and Kutahya–Simav, are characterized by Na–SO_4, Na–HCO_3, and Na–Cl–HCO_3, and enrichment, respectively, [37]. The chemical composition of the resource of pollution is discharged into the environment. In this way, geothermal fluids should be re-injected into the reservoir.

The Aydin–Germencik field is the most promising of these nine fields since, it has a power potential of at least 100 MWe. Therefore, a binary cycle power plant with an installed capacity of 25 MWe will be constructed soon at Aydin–Germencik. The BOT program for the Germencik field consists of five production wells and three re-injection wells. The total flow-rate is 1434 t/h, at a temperature of 210 °C, with a wellhead pressure of 15–18 bars [30].

There are plans to generate 500 and 1000 MWe from Kizildere, Germencik, Canakkale, Simav and several of the other fields by the years of 2010 and 2020 [36]. However, the application of these plans does not seem to be possible for now. Although the Aegean region includes rich high-enthalpy geothermal resources, there is one geothermal power plant already operating in the Denizli–Kizildere geothermal field and one is under the construction in the Aydin–Germencik geothermal field.

The country currently has only one operating geothermal power plant at Denizli–Kizildere fields where scaling has caused serious production problems. The Kizildere geothermal power plant was built and put into operation in February 1984. Its installed capacity is 20.4 MWe and its electrical energy generation capacity is approximately 105 GWh/year. The plant operates for 7000 h/year, with maintenance and mechanical cleaning of wells and equipment taking approximately 1760 h/year [38]. Because of scaling and pressure decreases in the second reservoir, the power plant is currently working at only about half of its installed capacity. Studies are also under way on the possibility of generating more power from the wastewater by using binary cycle plants.

4. Geothermal energy status and its assessment in the Simav region

Simav, located in the west of Turkey, has an area of 1687 km^2 and a population density of 47 persons/km^2. The Simav geothermal field, which includes thermal waters of Eynal, Citgol and Nasa, is located in the south of the Simav graben (39.0° latitude, 28.4° longitude) (Fig. 2). It is among the most important 15 geothermal fields of Turkey reaching a reservoir temperature of 162 °C. The temperature and capacity of these resources located at Simav–Eynal geothermal field is appropriate for founding an important geothermal complex. The geothermal fluid extracted from the well head at a temperature of 147 °C serves for thermal spring tourism besides district heating and greenhouse agriculture. The Simav district heating system has a capacity of 66 MWt [39]. A district heating system for residences began to operate in December 1992 and heats 3500 residences and 120,000 m^2 of greenhouses [27]. Studies are now assessing the potential to heat 6500 residences in Simav and possibility to generate electricity. The MTA has drilled wells of 65–958 m depths to make use of the geothermal potential of the area. Drilling studies in the Eynal thermal area showed that the area has a high geothermal potential with measured well bottom temperatures reaching 162 °C and a 72 kg/s artesian discharge rate. As can be seen in Table 4, some deep wells (E-1, EJ-2) have very low discharge rates and are now abandoned, although their bottom temperatures are very high. The well head temperatures

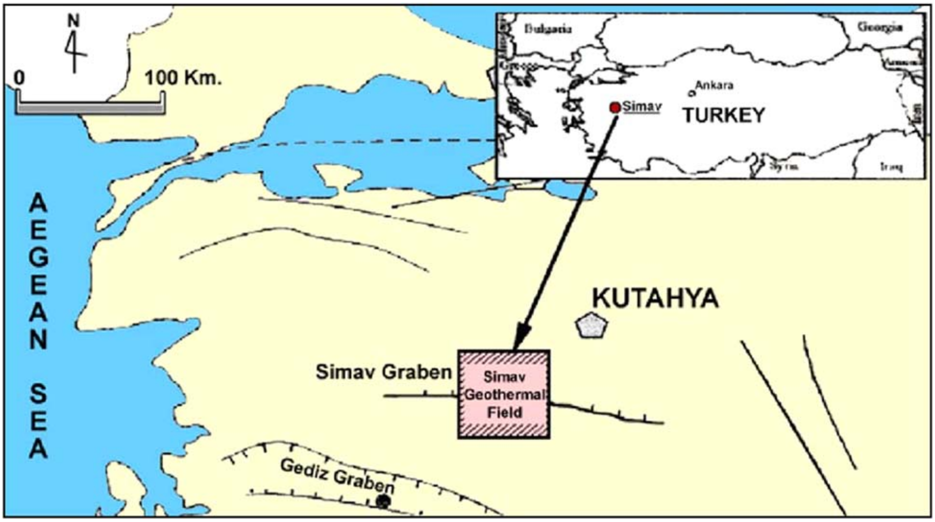

Fig. 2. Location of the study area (the Kutahya–Simav geothermal field).

Table 4
The geothermal potential of the study area [29]

Well number	Date	Depth (m)	Temperature (°C)	Discharge (kg/s)	Production type
E-1	1985	65.8	143 (WD)	14	A
E-2	1985	149.5	158 (WD)	55	A
E-3	1985	150	149 (WD)	50	A
E-4	1994	220	98	1	A
E-5	1995	300	97	6	A
E-6	1995	169	170	60	A
E-8	1996	225	150 (WD)	50	A
EJ-1	1990	725.2	162 (WD)	72	A
EJ-2	1990	958	158 (WD)	1	A
EJ-3	1991	450	150 (WD)	50	A

A, artesian; WD, well deep temperature.

of the production wells vary from 97–170 °C, while the discharge rates of the wells range from 1–72 kg/s.

The Simav geothermal district heating system is now fed only by the EJ-1 well, which is 725 m deep with a down hole temperature of 162 °C and 72 kg/s discharge of geothermal fluid. At the wellhead, the geothermal fluid has a temperature of 147 °C and a return temperature of 40 °C. The scaling and corrosion problems have been solved by an inhibitor (5 g per m^3) epoxy fiberglass pipe, 316 stainless steel plate type heat exchanged and partially by CO_2 and H_2S separation.

Sustainable production from the field will require careful management of the geothermal reservoir and an environmentally acceptable method must be found for disposing of the wastewater.

5. A design project of the power plant in the Simav–Eynal field

The electrical power from the geothermal energy was originally being produced from the steam resources above 150 °C. But it is now being produced from resources below 150 °C using the organic Rankine cycle process in binary power units in conjunction with a district-heating project [1,40–43]. Binary cycle plants are becoming more popular, because they can use lower temperatures, and the economics of the system is improved if the wastewater is used in a direct-use project such as district heating. The binary cycle system incorporates two distinct fluid loops. The geothermal fluid in the first loop transfers its heat to the working fluid in the second loop. The geothermal fluid releases its heat to the secondary fluid through the heat exchangers, where the secondary fluid receives heat and vaporizes. The vaporized working fluid drives the steam turbine, and then it is cooled and condensed. After condensing, the working fluid is returned to the heat exchanger, and the cycle begins again. By selecting suitable secondary fluids, binary systems can be designed to utilize geothermal fluids in the temperature range of 85–175 °C. The secondary fluid is operated through a conventional Rankine cycle. The used geothermal fluid is re-injected back into the reservoir to maintain reservoir pressure. The emissions of a binary geothermal power plant are minimum because the geothermal fluid is never exposed to the atmosphere [40–42].

The temperature of the geothermal fluid in the Simav–Eynal field is too high for the district heating system. Therefore, the potential of electrical energy generation by the binary cycle has been researched and the preliminary feasibility studies have been conducted in the field. The geothermal fluid, collected from the EJ-1 and the EJ-3 production wells in the Simav geothermal field are used for the design of the plant and the temperature of the geothermal fluid extracted from two production wells are considered to have a temperature of 145 °C with their capacity as 122 kg/s for the calculations.

Fig. 3 shows the scheme of the binary cycle studied in this paper. The main cycle components are; the geothermal fluid, the feed pump, the water re-injection system, the

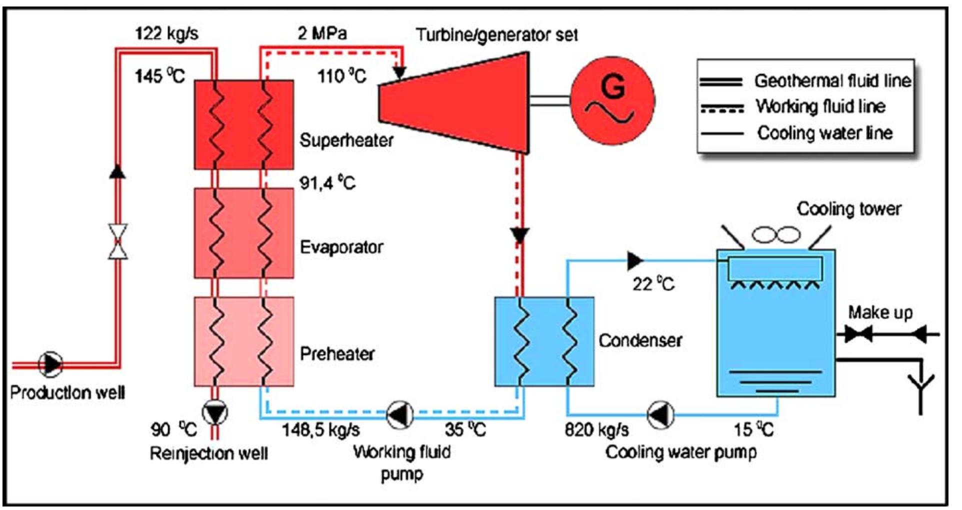

Fig. 3. Scheme of the Kutahya–Simav geothermal power plant.

organic Rankine cycle with pre-heater/evaporator/superheater, turbine/generator, condenser, and cooling tower. The geothermal brine (hot water is available at a nearly saturated state) is used as a heating fluid in a closed heat exchanger, which is the heat source for a closed Rankine cycle. This has the main advantage of avoiding the emissions of non-condensable gases to the atmosphere. Because this is a closed-loop system, virtually nothing is ejected to the atmosphere.

For the geothermal fluid, the thermodynamic properties of water are used. By doing so, the effects of any salt and non-condensable gases that might be present in the geothermal brine are neglected. This should not cause any significant errors in calculations since, their fractions are estimated by the plant management to be small. The temperature values at the well heads and the geothermal fluid heat capacity are assumed to be constant, although there is a variation in pressure and flow rate. All these calculations have been performed assuming the ambient temperature as 15 °C. The heat transfer coefficients in the heat exchangers, the efficiencies of the turbine, generator, and feed pump have been chosen.

Selection of a working fluid is an important task in designing a system. Usually, the working fluid is a hydrocarbon, such as the isopentane, or a refrigerant, such as R-12. Hydrocarbons have been used for a long time as the working fluid both in the cooling industry and binary cycle systems. They are low in toxicity and non-flammable, non-corrosive, and compatible with other materials. In addition, the thermodynamically and physical properties make them ideal for a variety of uses. However, chlorofluorocarbons (CFCs), coupled with their chlorine content, has linked them to depletion of the earth's protective ozone layer. As a result, DuPont is phasing out production of CFCs and introducing more environmentally acceptable alternatives, such as hydro chlorofluorocarbon (HCFC)-124. HCFC-124 may be used by itself as a pure refrigerant to replace R-114 in some applications, although its vapor pressure is somewhat higher than that of R-114. In addition, when replacing R-114 with HCFC-124, significantly higher refrigerant capacity will be needed. For environmental reasons, the working fluid used in this binary power plant is HCFC-124. This fluid has been chosen not only to make a direct comparison with the binary cycles, but it also has the convenient properties for its use in the Rankine cycles with the low temperature heat sources.

The system performs according to the ideal Rankine cycle and it is assumed that the pressure is constant in the interchange and condenser, and the fluid leaving the condenser enters the pump in the liquid phase. The geothermal fluid is led into the pre-heater, the evaporator, and the super heater. In these heat exchangers, working fluid receives the heat energy from geothermal fluid and the HCFC-124 liquid changes its phase to the HCFC-124 vapor phase. The HCFC-124 steam is led into the turbine rotator and than it returns back to the condenser, where it is cooled and changed to the HCFC-124 liquid phase. Thermodynamic and physical properties of HCFC-124 are shown in Table 5.

The heat exchanger transfers heat from the geothermal brine to the Rankine cycle fluid, which is pre-heated to the saturated liquid state, vaporized and finally superheated. The cooling water enters the condenser at 15 °C and exits at 22 °C, with a minimum temperature difference of 20 °C between the condenser and the cooling water. The turbine and pump efficiencies are chosen to be 0.85 and 0.90, respectively. All the components are treated as steady-flow devices, and any changes in kinetic and potential energies are assumed to be negligible. Since, this is a design analysis research, the above parameters are assumed to be constants for the calculations. While designing the plant, a packet program was drawn up using visual basic programming language in order to perform the

Table 5
Thermodynamic and physical properties for HCFC-124 [44,45]

Properties	Unit	HCFC-124
Refrigerant number	–	R-124
Replaces	–	R-114
Chemical formula/composition	–	$CHClFCF_3$
Molecular weight	–	136.48
Boiling point at 1 atm	°C	−12.1
Liquid density at 25 °C	kg/m^3	1401
Vapor pressure at 25 °C	kPa	386
Heat of vaporization at boiling point	kJ/kg	194
Heat capacity of liquid at 25 °C	kJ/kgK	1.13
Heat capacity of vapor at 25 °C	kJ/kgK	0.741
Thermal conductivity of liquid at 25 °C	W/mK	0.0722
Thermal conductivity of vapor at 1 atm	W/mK	0.0106
Critical temperature	°C	122.47
Critical pressure	kPa	3634
Critical volume	m^3/kg	0.00181
Critical density	kg/m^3	553.8

calculations quickly. With this packet program, the temperatures of certain points in the system can be found out and the heat amount to be transferred to the preheater/evaporator/superheater, the power to be obtained from the turbine and the capacity of cooling water to be used in the condenser can be calculated. Not only the parameters of the EJ-1 and the EJ-3 production wells but also the physical characteristics of water and HCFC-124 fluid used in the cycle, and the polynomial values related to temperature, are among the inputs of the program. The computer program prepared for the design is suitable for the use of other fluids instead of R 114 fluid [46].

Geothermal power plants are independent of climate and seasons. Climate conditions can influence the cooling capacity of some plants, but the general picture is that geothermal power plants can operate at constant day-out and day-in loads during the year. Therefore, it is convenient to operate the geothermal power plants with a base load when they are connected to a grid, together with the other types of power plants. It is assumed that the geothermal power plant operates for 8400 h/year, with maintenance and mechanical cleaning of wells and equipment taking approximately 360 h/year. There are many factors affecting the cost of geothermal power generation, including investment, capital structure, government policy and management capacity and skill. The lifetime of a geothermal power plant is 25 years and the construction period for a geothermal power plant is one year. Total initial investment in a geothermal power plant is US$ 1000/kW. Annual operating costs of a geothermal power plant account for 5% of the total initial investment.

6. Results and discussion

The geothermal energy has the potential to play an important role for the future energy supply of Turkey. Although, Turkey is the second country having the highest geothermal energy potential in Europe, the electrical energy generation from the geothermal energy is rather low. It is known that particularly the Aegean region includes the rich, high-enthalpy

geothermal resources. There is only one single-flash geothermal power plant in the region and a binary cycle power plant with an installed capacity of 25 MWe will be constructed soon at Aydin–Germencik.

Fig. 3 shows the flow diagram of the binary cycle studied in this study. It is assumed that HCFC-124 enters the pump at a temperature of 35 °C with a capacity of 148.5 kg/s. The pressure of the fluid entering the pump is the saturation pressure of the entrance temperature. The pump increases the pressure of the fluid to 2 MPa, which is the turbine entrance pressure. The friction of the working fluid causes pressure drops in the pre-heater, evaporator, super heater, condenser, and the pipes between the various components. As a result, the working fluid leaves the super heater at a lower pressure. Also, the pressure at the turbine inlet is lower than the one at the boiler exit due to the pressure drop in the connecting pipes. The pressure drop in the condenser is usually very small. The geothermal fluid in the cycle enters the super heater at the temperature of 145 °C with the flow rate capacity of 122 kg/s, and leaves the pre-heater at 90 °C, with the assumption that the phase of the geothermal fluid remains constant while entering and leaving the preheater, evaporator, and super heater in this research. The HCFC-124 fluid, exposed to a temperature of 110 °C in the evaporator, passes through the blades of the turbine to generate 3640 kWe power. The amount of the net electrical energy produced in the generator is calculated to be 2900 kWe. The thermal efficiency of the designed plant is measured to be 10.6% and the water capacity of its condenser is 820 kg/s. That is, this power plant converts 10.6% of the geothermal heat it receives in the heat exchanger to network. The heat from the geothermal fluid will be first utilized for electricity generation by the power plant then discharged at lower temperature (90 °C) to be further utilized for district heating. For this purpose, an integrated complex has been proposed there in order to use the energy of the geothermal fluid more efficiently. Owing to this complex, 10.6% of the geothermal energy can be converted into electrical energy and the rest of the remaining heat—89.4%—can be used for the residential heating in Simav. An actual power plant operating between the same temperature and pressure limits will have a lower efficiency because of the irreversibilities such as the friction. The technical characteristics of the Kutahya–Simav geothermal power plant are given in Table 6.

The optimization of the operating conditions of the cycle and changing the working fluid may lead to an increase in the performance of the designed plant. It is possible to increase the efficiency of previously constructed geothermal power plants considerably by using the current technologies. These technological improvements are the selection of another cycle for the plant, the optimization of its operating conditions, the change of working fluid in secondary cycles and the application of co-generation.

It has been concluded that the Kutahya–Simav geothermal power plant has the potential to produce an installed capacity of 2.9 MWe energy, and a minimum of 17,020 MWh/year (based on an estimated 67% utilization factor [47]) electrical energy can be produced from this plant. As a conclusion, the pre-feasibility study indicates that the project is economically feasible and applicable.

The use of geothermal energy for the electrical energy generation will further help to reduce our dependence on the fossil fuels, which are very expensive and also produce harmful emissions that are dangerous to our environment. In comparison to fossil fuels, geothermal energy has more advantages such as being renewable, reliable, clean, and a cheap domestic energy resource. Therefore, the development studies and investments in this sector should be supported.

Table 6
Technical characteristics of the Simav geothermal field and power plant

Parameter	Unit	Value
Reservoir temperature	°C	150–162
Operation pressure of wellhead	kPa	382.5
Wellhead temperature	°C	145
Total flow rate	kg/s	122
Geothermal power plant type		Binary cycle
Working fluid		HCFC-124
Working fluid flowrate	kg/s	148.5
Turbine inlet pressure	kPa	2000
Turbine inlet temperature	°C	110
The adiabatic efficiency of the turbine	%	85
The adiabatic efficiency of the pump	%	90
Condenser water capacity	kg/s	820
ΔT, Cooling water temperature	°C	7
Turbine power generation	kWe	3640
Generator power generation	kWe	2900
Annual produced electricity	MWh	24,360
Thermal efficiency	%	10.6

7. Conclusions

Turkey has a favorable basis for the wide-scale use of geothermal energy as one of the environment-friendly and sustainable renewable energy sources. Although the geothermal potential has been neglected so far in official documents, it is likely to gain a significant share for the electricity generation in many regions. Also, the geothermal power is home grown, reducing Turkey's dependence on foreign oil and natural gas. Present applications have shown that geothermal energy in Turkey and in other countries is clean and cheaper than the other fossil and renewable energy sources and therefore, is a promising alternative. It is clear that the present use of geothermal energy (105 GWh/year for electricity and 4465 GWh/year for direct use) is a very small fraction of the identified geothermal potential. Only 3% of the total geothermal potential of Turkey has been utilized so far. When Turkey uses all of this potential, it can meet 14% of its total energy need. Geothermal energy has the potential to play an important role in the future energy supply of Turkey.

It is not enough for the government to support the development of renewable energy technologies. The government must also support their commercial applications in the country. 170 geothermal wells have been drilled up to now in Turkey, which is a quite small number. Turkish geothermal law should be finalized as soon as possible, so that more geothermal wells can be drilled and the well risk can be taken by the state. A control mechanism should be established and more financing aids should be assigned for the geothermal development projects in Turkey.

The temperature of the geothermal fluid in Simav–Eynal field is too high for central heating. An integrated complex may be established there in order to use the energy of the geothermal fluid more efficiently. Thus, the researchers should focus on improving the efficiency of the cycles, developing new materials to be used in the system and developing

new environment-friendly methods for using the waste heat. This system can be used not only for recovering the geothermal energy but also for the power generation and is expected to make a great contribution to the prevention of the global warming and the energy saving as a power generating system.

Geothermal binary plants are relatively poor converters of heat into work. First law or thermal efficiencies typically lie in the range of 8–12%. Since efficiencies are low and economics questionable (high parasitic loads), these plants are often constructed in concerts with a district heating system. At present, it is possible to produce electricity easily with this fluid by using a binary cycle system. Consequently, because of the low thermal efficiency (10.6%) for the power plant studied here, the cogeneration systems and/or cascaded direct use of the waste heat is recommended. The rest of the heat (89.4%) can be used for district heating Simav, greenhouse agriculture and thermal tourism.

References

[1] Barbier E. Geothermal energy technology and current status: An overview. Renew Sustain Energy Rev 2002;6:3–65.

[2] International geothermal association. Available from http://iga.igg.cnr.it/geothermal.php

[3] US DOE. Overview of geothermal technologies. Renewable energy technology characterizations. Available from http://www.eren.doe.gov/power/pdfs/geo_overview.pdf

[4] Energy and geoscience institute at the university of Utah. Geothermal energy brochure. Available from http://www.egi.utah.edu/geothermal/geothermalbrochure.pdf

[5] Murphy H, Niitsuma H. Strategies for compensating for higher costs of geothermal electricity with environmental benefits. Geothermics 1999;28:693–711.

[6] Brophy P. Environmental advantages to the utilization of geothermal energy. Renew Energy 1997;10:367–77.

[7] Fridleifsson IB. Geothermal energy for the benefit of the people. Renew Sustain Energy Rev 2001;5:299–312.

[8] Kutscher CF. The status and future of geothermal electric power. National renewable energy laboratory, NREL/CP-550-28204, August 2000. Available from http://www.nrel.gov/geothermal/pdfs/28204.pdf

[9] US department of energy: Office of energy efficiency and renewable energy. Available from http://www.eren.doe.gov/geothermal/geopowerplants.html

[10] National renewable energy laboratory: Geothermal technologies program. Available from http://www.nrel.gov/geothermal/geoelectricity.html

[11] Bertani R. What is the geothermal potential, IGA news, quarterly no. 53, July–September 2003;1–3. Available from http://www.iga.igg.cnr.it/pdf/n53.pdf

[12] Huttrer GW. The status of world geothermal power generation 1995–2000. Geothermics 2001;30:1–27.

[13] Lund JW. World status of geothermal energy use overview 1995–1999. Available from http://geoheat.oit.edu/pdf/tp107.pdf

[14] Fridleifsson IB. Status of geothermal energy amongst the world's energy sources. IGA news 53, July–September 2003. Available from http://iga.igg.cnr.it/pdf/n53.pdf

[15] Lund JW. Hundred years of geothermal power production. GHC Bull 2004;11–19.

[16] International energy agency (IEA). Energy policies of IEA countries: Turkey 2001, review. Head of publications service, Paris: OECD, 2001. Available from http://www.iea.org/books/countries/2001/turkey.pdf

[17] The ministry of energy and natural resources (MENR). Energy report of Turkey. Ankara, Turkey 2003. Available from http://www.menr.gov.tr [in Turkish].

[18] World energy council turkish national committee (WECTNC). Energy report of Turkey in 2002. Ankara, Turkey: WEC-TNC 2003 [in Turkish].

[19] Kaygusuz K. Renewable and sustainable energy use in Turkey: A review. Renew Sustain Energy Rev 2002;6:339–66.

[20] Demirbas A. Turkey's energy overview beginning in the twenty-first century. Energy Convers Manage 2002;43:1877–87.

[21] Kincay O, Ozturk R. Thermal power plants in Turkey. Energy Sources 2003;25:135–51.

[22] Electric power resources survey and development administration (EIE). Potential of turkish hydroelectric, 2003. Available from http://www.eie.gov.tr/makale01.html
[23] Kose R. An evaluation of wind energy potential as a power generation source in Kutahya, Turkey. Energy Convers Manage 2004;45:1631–41.
[24] International energy agency (IEA). Renewables information 2003, international energy agency statistics. Paris: Head of Publications Service; 2003.
[25] World energy council turkish national committee (WECTNC). Energy statistics of Turkey in 2002. Ankara, Turkey: WEC-TNC 2003 [in Turkish].
[26] Fossil energy international, FE. An energy overview of the republic of Turkey. Available from http://www.fe.doe.gov/international/turkover.html, last updated on October 20, 2003.
[27] State planning organization (SPO). Electrical energy special commission report, eighth five-year development plan, Ankara, Turkey, 2001. Available from http://ekutup.dpt.gov.tr/enerji/oik585.pdf [in Turkish].
[28] Batık H, Koçak A, Akkuş İ, Şimşek S, Mertoğlu O, Dokuz İ, et al. Geothermal energy utilization development in Turkey—present geothermal situation and projections. Proceeding world geothermal congress 2000. Kyushu, Japan, May 28–June 10 2000. p. 85–912.
[29] General directorate of mineral research and exploration of Turkey (MTA). Turkish geothermal inventory, Ankara, Turkey, 1996. Available from http://www.mta.gov.tr [in Turkish].
[30] Mertoglu O, Bakir N, Kaya T. Geothermal applications in Turkey. Geothermics 2003;32:419–28.
[31] Turkish geothermal association, 2003. Available from http://www.jeotermaldernegi.org.tr, 2003 [in Turkish].
[32] Hepbasli A, Ozgener L. Development of geothermal energy utilization in Turkey: A review. Renew Sustain Energy Rev 2004;8:433–60.
[33] Kaygusuz K, Kaygusuz A. Geothermal energy in Turkey: The sustainable future. Renew Sustain Energy Rev 2004;8:545–63.
[34] The ministry of energy and natural resources of Turkey, MENR. Report of long term electric energy demand study of Turkey, 2005. Available from http://www.enerji.gov.tr
[35] Lund JW, Freeston DH. World-wide direct uses of geothermal energy 2000. Geothermics 2001;30:29–68.
[36] State planning organization (SPO). Geothermal energy special impression commission report, eighth five-year development plan, Ankara, Turkey, 2001. Available from http://ekutup.dpt.gov.tr/enerjiha/oik620.pdf [in Turkish].
[37] Erler YA, Larson LT. Genetic classification of gold occurrences of the Aegean region of Turkey. Proceedings of the international earth sciences congress on Aegean regions, Izmir, Turkey. vol. 1, 1992. p. 12–23.
[38] Simsek S, Yildirim N, Gulgor A. Development and environmental effects of the Kizildere geothermal power project, Turkey. Geothermics 2005;34:239–56.
[39] Mertoglu O, Basarir N. Geothermal utilization and applications in Turkey. Proceedings of WGC-1995 world geothermal congress, May 18–31, florence 1995. p. 345–50.
[40] Barbier E. Nature and technology of geothermal energy: a review. Renew Sustain Energy Rev 1997;1:1–69.
[41] Beck F, Shibaki M. Geothermal energy for electric power, A REPP issue brief, December 2003. Available from http://www.crest.org/articles/static/1/binaries/geothermal_issue_brief.pdf
[42] Dickson MH, Fanelli M. What is geothermal energy? IGA website, 2004. Available from http://iga.igg.cnr.it/documenti_igaenergia/geothermal%20energy.pdf
[43] DiPippo R. Second law assessment of binary plants generating power from low-temperature geothermal fluids. Geothermics 2004;33:565–86.
[44] DuPont Refrigerants, thermodynamic properties of HCFC-124, technical information. Available from http://www.dupont.com/suva/na/usa/literature/pdf/h47755.pdf
[45] DuPont HCFC-124 properties, uses, storage, and handling. Available from http://www.dupont.com/suva/na/usa/literature/pdf/pp6.pdf
[46] Kose R. Research on the generation of electricity from the geothermal resources in Simav region, Turkey. Renew Energy 2005;30:1–13.
[47] Turkenburg WC. Current status and potential future costs of renewable energy technologies, Table 7.25. World energy assessment: Energy and the challenge of sustainability. Prepared by UNDP, UN-DESA and world energy council. United nations development programme, New York; 2000.